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JOINT ENHANCED ROTORCRAFT TEST AND OPERATIONAL CAPABILITY (JERTOC)

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ABSTRACT

The DoD procurement account fell by more than 70% during the past decade [1]. The cost associated with the next generation of rotorcraft design, analysis, testing, training, and support, using current techniques, promises to escalate in a predicted hostile fiscal environment. This cost must be reduced through the use of credible simulation and other analytical options. Conventional multi-service air vehicle flight testing is becoming more expensive and the test results may uncover problems late in the acquisition cycle, where making changes can be both costly and time consuming. Mission rehearsal training is normally conducted on operational flight trainers far removed from the battlefield site. A need exists to conduct joint service air vehicle testing analytically first, and to do mission rehearsal training at deployed sites. A need also exists to help integrate the design and test phases of the aircraft acquisition cycle and to do flight testing better, faster, cheaper, and safer. The JERTOC concept was formulated as one approach to help realize the generic better/faster/cheaper/safer criteria applied to test and evaluation (T&E), as well as, to help achieve local flight test objectives of reducing TE cost and cycle time. The JERTOC concept involves testing and evaluating advanced technology programs in aircraft and engine simulation modeling, design, test planning, and test reporting to better support acquisition, testing and training in an integrated environment. An initial goal of this program concept is to develop the capability to do analytically in one month what might currently take more than a year of actual air vehicle flight testing. A final goal includes using the capability of a high performance computing (HPC) center to analytically run a helicopter air vehicle test program in one 24 hr period. This enhanced capability would not be used to replace actual flight testing, but would be used as a flight test planning tool to help predict flight results, identify potential flight limitations, and improve flight test safety.

BACKGROUND

Aircraft testing and the associated training and support place large demands on flight vehicles, avionics, weapon systems, team personnel, and scarce fiscal resources. Factors such as declining budgets, reduced staffs, increased project cost, and tightened delivery schedules all point to the need to improve the current flight test process. Joint Vision 2010 calls for full spectrum dominance, which implies a need for increased operational readiness and flexibility. Vision 21 [2] calls for a reduction in the current test and evaluation (T&E) infrastructure cost. The Simulation, Test and Evaluation Process (STEP) [3] and DoD Regulation 5000.2-R [4] require modeling and

simulation throughout the system life cycle. Zittel [5] reviews the DoD Simulation Support Plan that calls for "… increasing emphasis on the use of modeling and simulation (M&S) in our acquisition programs to reduce cost and schedule without sacrificing quality or performance." Simulation based acquisition is considered an effective, affordable mechanism for fielding complex technologies, and may help to make DoD a "smart buyer" [6]. Flight test enhancement options, focusing on simulation, may play a role in reducing the cost and time required to test the next generation aircraft and related systems. Current rotorcraft simulation models are typically vehicle specific and do not have the high fidelity rotor and fuselage components required to accurately predict loads. Current engine models are limited in their ability to predict dynamic events like compressor stall, are typically implemented for specific engines, and have little or no design capability. The current generation of T&E simulation models does not provide insight into the overall aircraft/system design process. The current modeling environment does not support helicopter/ship operational envelope development due to limitations in aircraft modeling and ship environment modeling.

INTRODUCTION

The JERTOC concept involves enhancing and integrating advanced technology programs in aircraft and engine simulation modeling, design, test planning, and test reporting to better support acquisition, testing and training. An initial goal of this program concept is to develop the capability to do analytically in one month what might currently take more than a year of actual air vehicle flight testing. A final goal includes using the capability of a high performance computing (HPC) center to analytically run a helicopter air vehicle test program in one 24 hr period. The complexity of helicopter rotor models and related loads and inflow modules, fuselage models, and engine models, plus associated ship airwake models, require improved software and high performance computing hardware. This program involves integrating and enhancing advanced technology programs in aircraft and engine modeling, design, and flight test automation to form a unified environment to enhance rotorcraft testing in land and shipboard environments. This unified environment could be used to support current and next generation aircraft/systems design and testing. The JERTOC program initial focus is on testing, validating and applying the technology developed to the multi-service H-60 helicopter. The generic nature of the technology developed make it readily adaptable to other rotorcraft, unmanned aerial vehicles, or fixed wing aircraft as required. The major program components include testing and validating enhanced and integrated modules in:

- Air vehicle and engine simulation
- Design simulation
- Flight test plan and report automation
- VV&A with built-in validation
- 3-D component modeling options
- Specific vehicle and mission application

AIR VEHICLE SIMULATION

If there was only one vehicle to simulate, which some people have theorized may be the case in about 2050 [6], the simulation challenge would be relatively small, and there would be no requirement for a standard or generic simulation structure. The DoD Director Test, Systems

Engineering and Evaluation web page (www.acq.osd.mil/te/programs/msse.html) under the Modeling and Simulation Software Vision and Initiatives discusses providing modern, cost effective tools and methods. It notes that a survey revealed that 900 models and simulations were being used (600 different models), which was noted as "too many." The American Helicopter Society Dynamics Committee Workshop on Rotor Dynamics Analysis [7] compared the ability of 8 advanced aeroelastic rotorcraft codes to predict vibratory rotor hub loads in 1996. The initial study results indicated that, on average, the codes were not able to predict vibratory loads to an accuracy any greater than 50% of the measured loads. The final study results noted that the accuracy of one code was improved to 75%, but that accuracy was still considered unacceptable. Although numerous models exist, many model limitations exist which limit their ability to support rotorcraft flight testing. It appears that some aerodynamic and/or structural components may be missing in the model development.

A Navy flight test activity may work with a wide variety of fixed-wing aircraft, rotorcraft, and UAV's, plus related systems. If the activity had the world's best AH-1W model, it could not be used to support H-46 testing, training, or mission rehearsal. If the activity had a good H-46 model, it could not be used to support H-60 test programs. In this case, having a generic model structure, with a standard model input data format could be used to facilitate model set-up. The model complexity level could be selectable as shown in figure 1. A physics-based generic structure simulation model, with selectable levels of fidelity, has the potential to support testing on a wide variety of multi-service rotorcraft. Elastic rotor blade and fuselage components, combined with computational fluid dynamics (CFD) engine and ship airwake models, require high performance computing (HPC) hardware. Code enhancements are required to better support basic flying qualities and performance testing, helicopter/ship dynamic interface testing, and reliability and maintainability testing. The HPC system hardware can be used to support real-time test team training or numerous parameter sweeps at each data point using a complex aircraft model. This parameter sweep information can be used to provide quick answers to sponsors' questions on "What happens if I change ...X... or ...Y... on my aircraft?" The ability to do comprehensive flight test programs and design trade-off studies analytically has a potential for large savings in the test community. The generic nature of the proposed software makes it portable, scaleable, and reusable. It also satisfies the high priority DoD requirement to do testing better, faster, and cheaper, and to help reduce the overall test and evaluation infrastructure cost for each test program.

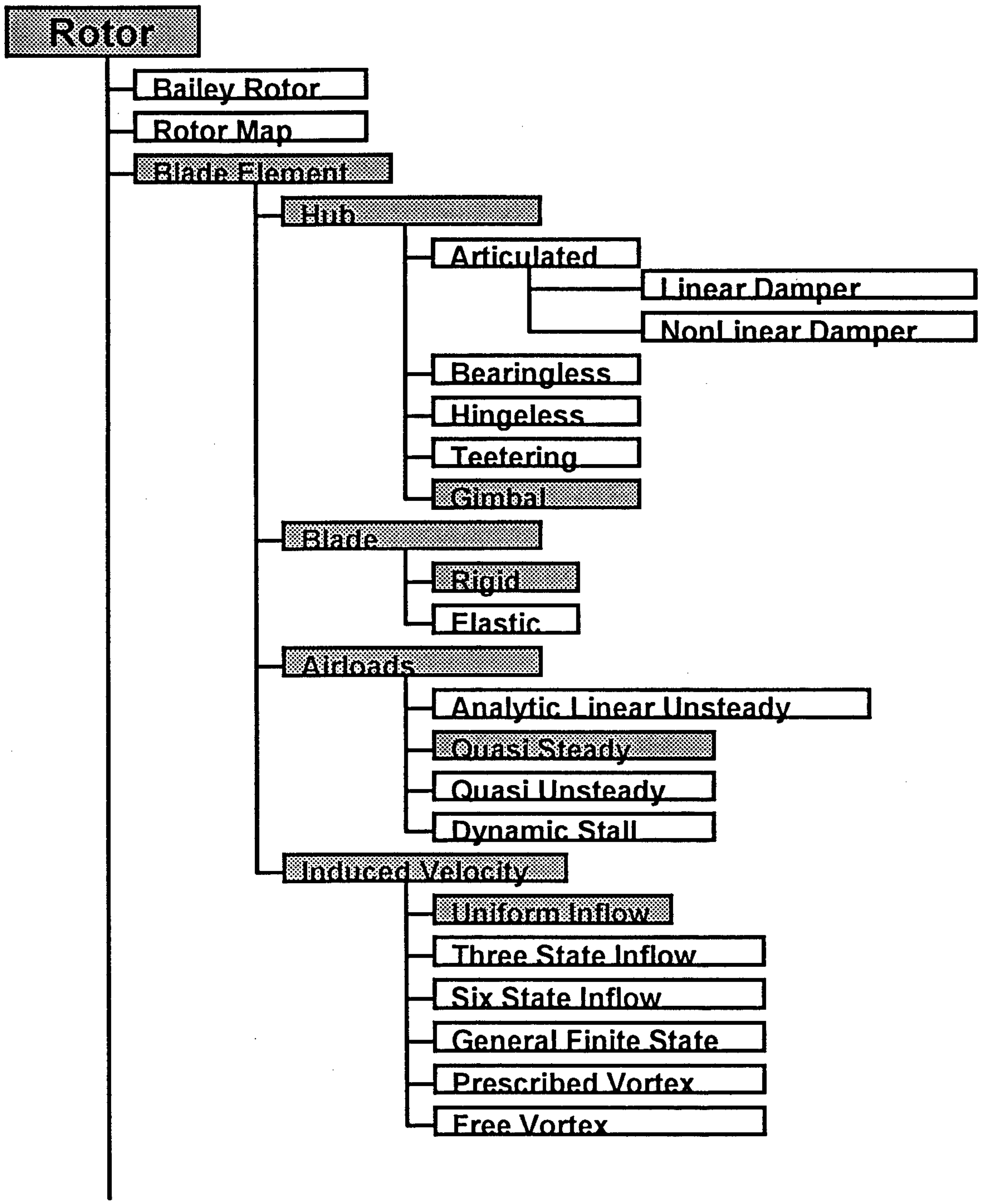


Figure 1
Rotor Model Sample Levels of Complexity

ENGINE SIMULATION

The engine is a key aircraft component and provides power for all flight regimes except autorotation. The engine power available is important for performance and for mission operational analysis. Engine models are typically designed for a specific engine and may not be readily adapted to other engines. The aerodynamic turbine engine code (ATEC) is used to support Air Force turbo jet engine testing at the Arnold Engineering Development Center (AEDC). The ATEC program simulates the operation of gas turbine engines by solving conservation equations, expressed as one-dimensional, time-dependent, Euler equations, with turbomachinary source terms [8], as shown in figure 2. By incorporating both implicit and explicit equation solvers, transient simulations of the gas turbine engine can be conducted while maintaining the capability of simulating dynamic events like compressor stall. One limitation common in current rotorcraft simulation engine models is that the thermodynamics of the gas generator and power turbine are quasistatically represented using look-up tables obtained from experimental testing. The ATEC program includes CFD modeling of the gas generator. This permits modeling the engine component thermodynamic transients and provides a physically based approach to engine modeling.

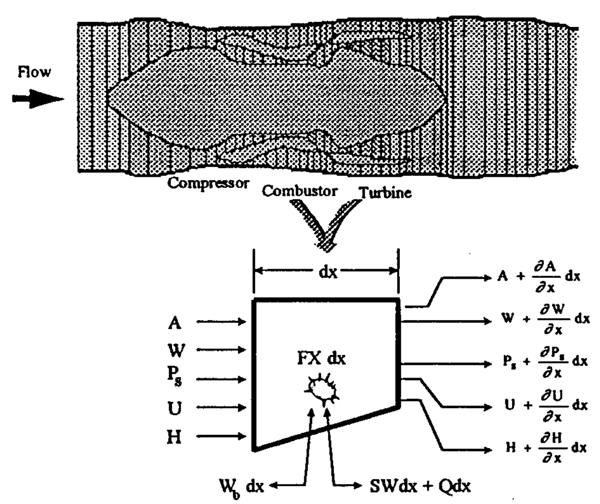
- The Aerodynamic Turbine Engine Code solves the 1-D Euler Equations with Turbomachinery Source Terms across elemental control volumes:

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{G}$$

where:

$$\mathbf{U} = \begin{bmatrix} A\rho \\ \rho A u \\ AE \end{bmatrix} \quad \mathbf{F} = \begin{bmatrix} \rho A u \\ \rho A u^2 + AP \\ u(AE + AP) \end{bmatrix} \quad \mathbf{G} = \begin{bmatrix} -W_{B_x} \\ F_x \\ Q_x + SW_x - H_{Bx} \end{bmatrix}$$

- Variable time-stepping routine using both explicit and implicit numerical solvers ensures efficient transient simulation with high fidelity dynamic simulation



Discretization of system into elemental control volumes

Figure 2
AEDC Aerodynamic Turbine Engine Code

DESIGN SIMULATION

A significant life cycle cost payoff could be achieved using an integrated product and process design approach applied to the next generation aircraft design and acquisition programs [9-10]. The acquisition life cycle payoff is determined using a robust design simulation methodology that incorporates all related elements into an integrated framework. An example is shown in figure 3. The central element of the aircraft design program is a synthesis/sizing module that creates a sized vehicle capable of fulfilling all mission requirements. The vehicle is sized using an overall evaluation criterion which captures all the important system attributes including affordability, mission capability, operational availability, survivability, and operational safety.

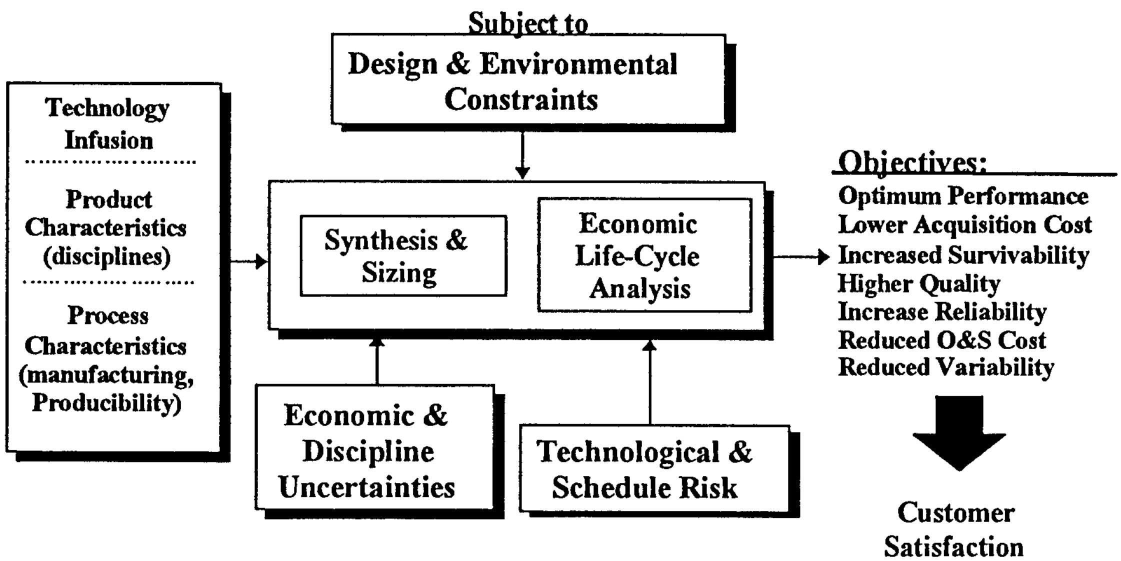


Figure 3
Robust Design Simulation

FLIGHT TEST AUTOMATION

The Navy initiated a low-key, in-house program at Patuxent River, MD., in 1987 that focused on using new computer software to support fixed-wing electro-optics test plan development. The program focus shifted to rotorcraft helicopter/ship and flying qualities and performance testing in FY89, and the concept was called the Test Plan Automation System (TPAS). Different expert shell structures were evaluated and limited work was performed to input flight test knowledge base information into the TPAS system. Funding for this initial in-house work ended in 1992, and in 1994 a small business innovative research (SBIR) program was initiated that renewed the effort. The SBIR work focused on using artificial intelligence technology to enhance rotorcraft test planning, test reporting, data analysis, and project management. This SBIR program project was called the Automated Flight Test Engineering System (AFTES). The initial work on the

AFTES focused on acquiring sample rotorcraft flight test plans for the program knowledge base, and on developing the ability to rapidly generate a comprehensive test plan. The initial program focus has been on developing the capability to support helicopter/ship or Dynamic Interface (DI) test planning. Additional work is needed to extend the application to flying qualities and performance (FQ&P), avionics and other types of rotorcraft testing.

If specific type DI tests are selected, and the input field data inserted, and the generate test plan option selected, AFTES will take about 15 minutes on a Pentium PC to generate a comprehensive test plan of about 90 pages, including checklists and lessons learned. If specific air vehicle simulation parameters (gross weight and center of gravity) and atmosphere parameters (wind speed and direction, altitude, and temperature) are selected for parameter variation sweeps, the calculations could easily take over a month of CPU time on a typical workstation. If specific applications include real time helicopter/ship modeling, high performance computing hardware are required.

VERIFICATION, VALIDATION AND ACCREDITATION (VV&A)

VV&A is required as a sanity check of the basic model structure to determine if acceptable protocol was used in the model development, and to determine applications for which the model has been approved. Verification refers to determining that the overall model and its components have been implemented or programmed correctly. Validation refers to the process of determining how close the model compares to real world data. Accreditation refers to the process of approving the model use for specific applications. Formal VV&A definitions are available in current modeling and simulation literature [11-12]. From a flight test perspective, validation plays a big role in model acceptance and use. It is easy for one group to challenge the validity of another group's model, and getting only qualitative assurance from the model developers, call the model "not validated." Navy operational flight trainers (OFT) and weapon systems trainers (WST) are evaluated by flight test teams using flight test criteria data with a format derived primarily from the Navy Test Pilot School (NTPS) rotary wing performance and stability and control manuals [13 - 14]. Rotorcraft air vehicle and OFT are evaluated using quantitative and qualitative test techniques specified in the USNTPS flight test manuals. Data formats corresponding to these standard techniques could be built into the simulation model structure and when questions surfaced on a particular type test, the model user could view available test data and run the model at the same conditions. This basic built in check, combined with advanced techniques to be developed, could be used to help provide a high degree of model acceptance from the user community.

3-D COMPONENT MODELING

The flight test community works in a 3-D world, and rotorcraft and other aircraft fly in a 3-D world. Most of the model development and analysis is performed in a 2-D world. It is important to be able to work with primitive components associated with the model to be developed. For rotorcraft model development these components might include hinges, springs, and dampers, plus translate, mass, inertia, 2-D and 3-D airfoils, and other components. The programmer could connect the appropriate components to develop a model of a helicopter rotor blade. The person who developed the blade model could look at it and readily identify it as a rotor blade. Flight test engineers typically think of a

rotor blade as having a specific physical size and shape, which includes span, chord, airfoil(s), twist, tip configuration, and hinge configurations, plus mass and inertia. Being able to construct and test a 3-D helicopter model would give the flight test engineer an insight currently not available in most helicopter simulation models.

SPECIFIC APPLICATION - ROTORCRAFT SHIPBOARD TESTING

Navy at-sea scenarios can present unique flight test requirements, as shown in figure 4. Environmental factors like ship wind-over-the-deck speed and direction, and ship motion are difficult to control [15]. Helicopter/ship or Dynamic Interface (DI) operational envelope testing is expensive, and it is not possible to control the weather to get high relative winds and sea states. The capability to develop helicopter/ship operational flight envelopes analytically would help re-invent at-sea testing by allowing it to be done better, faster, cheaper, and safer. Analytical approaches to DI testing have been suggested since 1984 [16], but this capability currently does not exist. The current rotorcraft operational flight trainers costing up to approximately $60M are very limited in their ability to support DI testing. Primary simulation factors needing improvement include ship airwake, rotorcraft aerodynamic interference, and visual systems. The minimum level of cues required for using a simulator to support shipboard landing training and testing also needs to be defined. Several related ongoing efforts are looking at computational fluid dynamics and other approaches to ship airwake modeling.

Figure 4
H-60 Landing Aboard Destroyer

INTEGRATION

The JERTOC concept focuses on evaluating and validating advanced software in rotorcraft air vehicle and engine simulation, design, flight testing and training. The concept starts with a high fidelity rotorcraft simulation code that has the best chance to accomplish the program objectives with the least amount of enhancement and with a minimum of potential limitations of the basic structure to the integration process. Component areas to be enhanced, evaluated, and validated include the following: design, load predictions, CFD engine, test plan/report automation, VV&A, flight test interface and 3-D component modeling capability. The basic model structure should be relatively easy to set up for a variety of multi-service rotorcraft and other aircraft, and it should include elastic rotor and non-linear structures and vortex wake modeling options for both non-real time and real time analysis and simulation. One potential JERETOC integration approach is illustrated in figure 5.

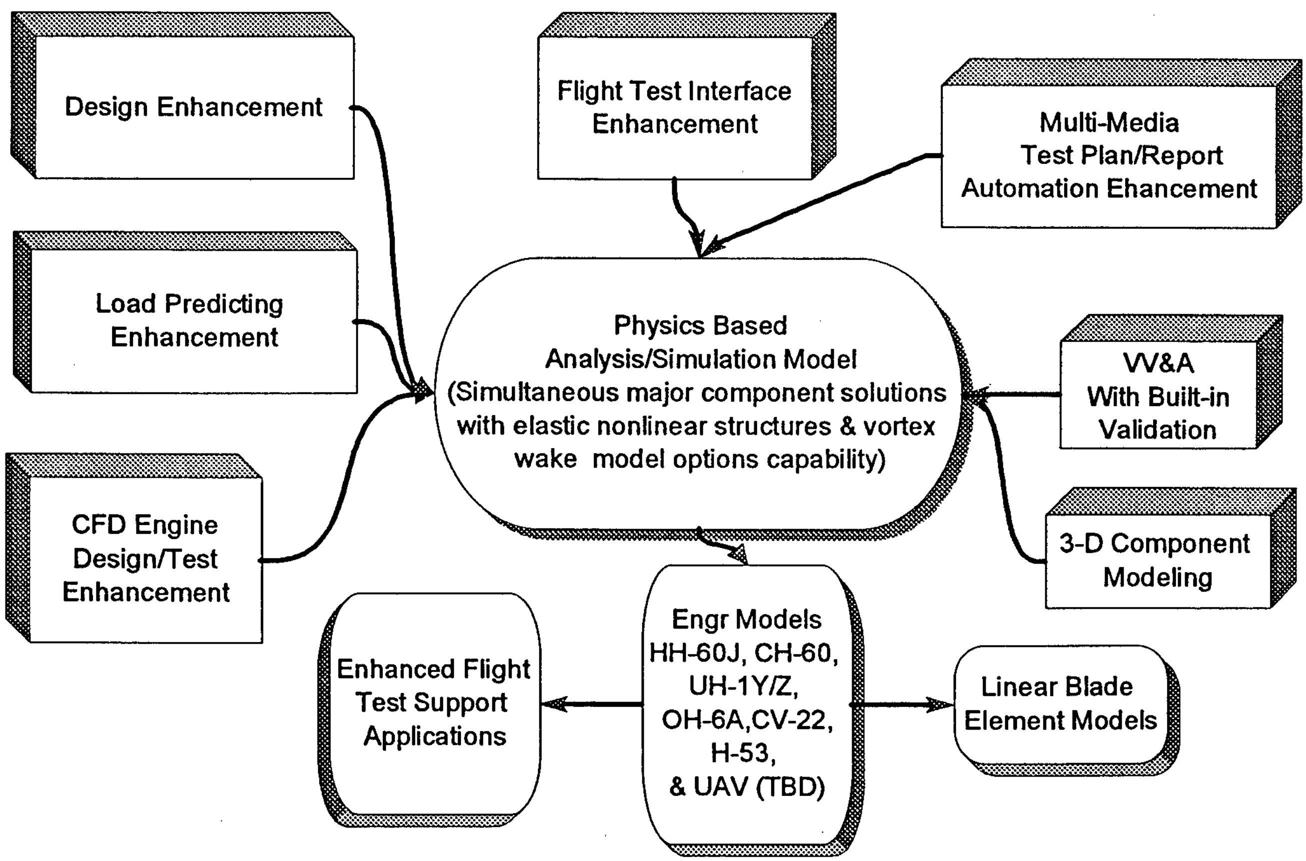


Figure 5
JERTOC Component Integration

SUMMARY

The JERTOC program concept presents one option for using advanced simulation software interfaced with high performance computing hardware to help enhance aircraft/systems testing. This program also leverages the related technology developed by several ongoing small business research programs and limited direct task work, which has been performed without the benefit of HPC. Rotorcraft simulation model enhancements are required to better support flight testing with emphasis on supporting loads testing and rotorcraft/ship interface testing. Elastic rotor blade and fuselage components, combined with CFD engine modules, and complex ship airwake models, will require HPC hardware for quick response time needed to support flight testing. The JERTOC program concept involves evaluating and validating an enhanced generic structure simulation model that has a good multi-service/industry/academia technology background. The availability of HPC hardware can now be used to generate a new level of flight test support with modeling and simulation, if the appropriate software is available. This program will produce an enhanced software capability to run a complete rotorcraft air vehicle flight test program analytically and do design trade-off studies while generating the test plan. The ability to do flight test programs first analytically will allow future flight testing to be done better, faster, cheaper, and safer.

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Biographies

Dean Carico is an aerospace engineer in the rotorcraft shipboard suitability group in testing and evaluation engineering at the Naval Air Warfare Center Patuxent River, MD. Dean initiated the flight test automation using high performance computing program, the rotorcraft simulation to support flight testing program, and over fifteen small business innovative research programs that focus on enhancing rotorcraft flight testing. Dean has masters degrees in Aerospace Engineering from Princeton and in Engineering Science from the Navy Postgraduate School, and is an engineering graduate from the USNTPS. He received the Meritorious Civilian Service Award for testing in a combat zone in 1973, and the Richard L. Wernecke Award for technical excellence in rotorcraft test and evaluation in 1997.

Chuck Slade is a mechanical engineer in the rotorcraft shipboard suitability branch at the Naval Air Warfare Center at Patuxent River, MD. Chuck has served as project engineer on several rotorcraft/ship test programs and the technical monitor on related small business research programs. He has an MS in mechanical engineering from Syracuse, and is currently attending the US Naval Test Pilot School.

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